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Performance Characteristics of a "Bulk Effect" Humidity Sensor

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Performance Characteristics of a

"Bulk Effect" Humidity Sensor[a] [1]

by

James W. Little

Saburo Hasegawa

and

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Abstract

A laboratory study was made of the performance of "Brady Array"
humidity sensors[b] over a range of ambient temperatures from -40°C to
+20°C encompassing relative humidities from 0 to 90 percent. Information
was obtained on such characteristics as sensitivity, hysteresis,
temperature effect, short-term and long-term repeatability.

Key words: "Brady Array" sensors, electric hygrometer, humidity,
humidity sensor, moisture measurement, relative humidity, water vapor
measurement.

1. Introduction

The National Bureau of Standards was asked to select and study the performance characteristics of several humidity sensors for possible use in the Department of Transportation Climatic Impact Assessment Program (CIAP) [2,3,4][c]. The results of tests on two types of aluminum oxide sensor were reported by Hasegawa et al [5]. The purpose of this paper is to report on the results of the "Brady Array" humidity sensor [1].

2. Description of Sensor

The manufacturer categorizes this sensor as a solid-state semiconductor device comprising "a precise array of crystals and interstitial spaces." It is mounted within a slotted TO-5 transistor enclosure. An excitation oscillator, driven by a dc input of 15 volts, provides a 5-volt rms 1000-Hz signal to the sensor and a demodulator provides a dc output signal varying in magnitude from 0 to 5 volts. This dc signal was measured with a digital voltmeter calibrated to within ± 0.3 mV or less for all measurements reported here. Each of two excitation oscillators was connected through appropriate cables to five sensors and demodulators.

[c]. Figures in brackets indicate the literature references at the end of this report.

3. Test Procedure

The test procedure and test equipment have been described in detail in the earlier paper [5]. Briefly, ten sensors[d] were subjected to atmospheric air of known relative humidity. First, a series of runs was made on five of these sensors (Nos. 6 through 10) at ambient temperatures of −40° and −60°C in the NBS low frost-point generator [6]. It was soon apparent that the sensors were insensitive to changes in humidity at these temperatures. Therefore, further testing at these low temperatures in this apparatus was discontinued. During this series of tests, these five sensors were inadvertently exposed to conditions of saturation (with respect to ice) at temperatures below −60°C. Other than on this occasion, none of sensors was subjected to relative humidities in excess of 90.3 percent with respect to either water or ice.

A second series of runs was made on all ten sensors using the NBS two-pressure humidity generator [7] for producing a range of humidities at ambient temperatures from +20 to −40°C. A list of the test spans at the various ambient temperatures is given in Table 1 in both relative humidity and dew/frost point.

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[d] Ten "Brady Array" sensors, Model BR-101, were obtained with the circuitry to operate these sensors. The manufacturer was informed that these sensors were to be tested and evaluated at temperatures down to −70°C. These sensors were purposely obtained without built-in temperature compensation.

4. Results

A family of calibration curves is shown in Figure 1 for sensor
No. 2, which had a sensitivity close to the average of all sensors. The
output in volts has been plotted against relative humidity with respect
to water at ambient temperatures of 20, 0, -20 and -40°C. There is a
displacement of each isotherm downward (a diminution in output voltage
at a given relative humidity) as well as a loss in sensitivity (a decrease
in output voltage change per unit change in relative humidity) with
decreasing ambient temperature. A corresponding family of calibration
curves for sensor No. 2 with the output in volts plotted against dew/frost
point is shown in Figure 2. At -40°C ambient temperature, the sensor is
quite insensitive both in terms of relative humidity and in terms of dew/
frost point.

The manufacturer sells these sensors as relative humidity measuring
instruments and provides calibration curves in terms of relative humidity
vs voltage output or impedance. Therefore, relative humidity with respect
to water will be considered the measurand in all cases and will be used as
the dependent variable in all of the subsequent mathematical analyses.
Where dew/frost points are given, as in Figure 2, they will be conversions
for the convenience of the reader.

Table 2 is a compilation of the sensitivities of each sensor at the four ambient test temperatures at various relative humidities in units of mV/percent r.h. The sensitivities were obtained by differentiating the calibration equation and solving the differentiated equation at voltages corresponding to the indicated relative humidities. The method of obtaining these equations as well as others used in the analysis of the sensor performance is given in the Appendix.

Due to the fact that these sensitivities are based on limited numbers of calibration points subject to various influences and errors, no great significance can be placed on individual values. The sensors in general are most sensitive in the upper (higher) half of the relative humidity range and at the higher ambient temperatures. At -40°C, the sensitivity is so small that there is likely no significance to the sensitivity data.

Temperature coefficients are given in Tables 3 and 4 for each of the ten sensors. These express the average change in relative humidity per degree change in ambient temperature for selected spans of output voltage, that is, they are a measure of the shift in indicated r.h. that one would expect due to a change in ambient temperature. The values listed in Table 3 were calculated from the 20 and 0°C isotherms; the values listed in Table 4 similarly were calculated from the 0°C and -20°C isotherms. The method of calculating the coefficients is explained in the appendix.

In each table, column 2 tabulates the selected span of output voltage, columns 3 and 4 show the relative humidity limits corresponding to the end points of the selected span of output voltage for each of the two isotherms and column 5 gives the mean temperature coefficient for the selected span of output voltage.

Hysteresis loops, at ambient temperatures of 20, 0 and -20°C, for sensor No. 2 are plotted in Figure 3. Each loop was obtained without prior humidity cycling at the specified temperature and so will be referred to as the first cycle hysteresis loop. Starting from an initial "rest" position, the relative humidity was changed monotonically to some final value and then returned monotonically to the initial point, with pauses along the loop for reading the output voltage of the sensor. At -40°C, completed loops were not obtained in one day and no curve is shown. Hysteresis data for all sensors are given in Table 5. For any output voltage, the difference in relative humidity between the increasing and decreasing r. h. branches of the loop is defined as the hysteresis. The order of the limits in the span in Table 5 indicates the direction of the first leg of the hysteresis loop. The mean value is the mean of the differences in relative humidity indication at identical output voltages between the increasing humidity leg and the decreasing humidity leg over the humidity span. The |Max| value is the maximum absolute difference in relative humidity over the range of output voltages used. The method of computation is described in the Appendix.

At -40°C, there is no true hysteresis loop data, since only single leg calibrations were made at any one time. Similar calculations were therefore performed on an open loop which consisted of two first cycle legs starting at opposite limits of the span and proceeding in opposite directions to the other limit.

With the exception of the high humidity span at 0°C, the mean hysteresis for the ten sensors is approximately 10 percent of the upper humidity limit for limits in excess of 15 percent r.h. In the case of the high humidity span at 0°C, it will be noted that the direction of r.h. change of the hysteresis loop is opposite from that of the other loops. In addition, the relative humidity surrounding the sensor was brought from a low value to the indicated high value before measurements were commenced resulting in mean and maximum values of hysteresis appreciably less than comparable values at other ambient temperatures. What is calculated as hysteresis at very low values of relative humidity is in a direction opposite to that which can be assigned to hysteresis and suggests that other factors besides immediate past history influence the output of the sensor .

In order to obtain a better estimate of the effect of the direction
of humidity change on the sensor, separate calibration curves were derived
for increasing and decreasing changes in humidity, using all available
data obtained in a given direction, for the sensors at 20, 0 and -20°C.
Because these curves include data from all test spans they are probably
the best overall calibration of the sensors from the available data. Other
factors influencing sensor output are more balanced in these curves than
in the hysteresis curves. Analysis of the directional calibration curves
was performed in a manner similar to the analysis of hysteresis and the
results are tabulated in Table 6. The spans used were selected from
the calibration data available meeting the criterion of having previous
points at lower humidities for the increasing humidity curve and previous
points at higher humidities for the decreasing humidity curve. The results
show the importance of a knowledge of prior history whenever a measurement
is performed with these sensors.

Short term repeatability is shown in figure 4 for sensor No. 2 and
for all sensors in Table 7. The values were obtained by comparing two
similar calibration curves taken one day apart except at -40°C where, due
to the increased time required to perform a calibration, the calibration
curves were taken three days apart. The shift in output over a period
approximating a day was such as to give higher voltage outputs for the same
relative humidities, which has the effect of indicating lower humidities
at the same voltage output.

Although the reliability of any individual value is probably not very great due to the scatter of individual calibration points, it is significant that all shifts were in the same direction, except for two sensors at -40°C, and that the composite mean of all sensors is approximately the same at all ambient temperatures.

Long term repeatability is shown in figure 5 for sensor No. 2 and for all sensors except No. 1 in Table 8. Due to the failure of a connection in the measuring circuitry, the final data on sensor No. 1 was not obtained. The procedure is the same as that used for short term repeatability except that in this case the calibrations were performed five months apart with the sensors unused and stored in their original containers at room conditions during this period. Room conditions during storage were approximately 24°C and 40 percent relative humidity. These long term repeat calibrations were performed only at 20 and -40°C. At -40°C ambient temperature, the long term shift was so great that there was a duplicated output voltage range with only three sensors as is shown in Table 8.

With the exception of Sensor No. 4, the long term shift is in the opposite direction of the short term shift and is approximately twice as great in magnitude.

An estimate of calibration scatter is given in Table 9. This was obtained by fitting calibration points taken with increasing relative humidities to a cubic equation by the method of least squares and calculating the standard deviation of the fit. This selection of calibration points gave the smallest estimates of standard deviation and is an indication of the scatter in a calibration. The larger value obtained for the standard deviation at −40°C is no doubt due to the very low sensitivity at that temperature and confirms the fact that there is very little valid quantitative information available on what effect various factors have on sensor behavior at −40°C.

At the other ambient temperatures, the scatter is much smaller and fairly constant. The value of this scatter can be used as a measure of the significance of the effect of the other factors which have been estimated.

5. Conclusions and Discussion

There was great variability in the set of ten sensors used in this study. The sensitivity of individual sensors varied by a factor of at least three. It is therefore apparent that individual calibrations for each sensor are required. The calibration curves tend to be S-shaped and can be approximated by cubic equations. This shape is typical of relative humidity sensors and results in considerably reduced sensitivity at low relative humidities. The sensor would therefore appear to be more appropriate for use at moderate or high relative humidities.

There is a considerable ambient temperature effect on the performance of these sensors. Not only is there a shift in the calibration curve with temperature, but also a diminution of sensitivity with decreasing ambient temperature. This diminution is very great at -40°C. In addition, the ambient temperature coefficient of the various sensors varies by a factor of approximately three. It is therefore necessary that each sensor be calibrated over the ambient temperature range of intended use. The temperature coefficient varies with ambient temperature sufficiently to require calibration at fairly close ambient temperatures.

The hysteresis of these sensors is appreciable. Although there are some values of hysteresis given in Table 5 which are very modest, it will be noted that these values are a large part of the value of the humidity range to which they apply. The direction effect values given in Table 6 are probably a more significant indication of the hysteresis effect and average about 9 percent of the maximum humidity in the applicable range. No direction effect is given for -40°C because there were insufficient calibration points to provide the same type of analysis as provided for the other ambient temperatures. The open loop hysteresis values for -40°C given in Table 5 can be taken as an approximation to the missing values in Table 6 and are consistent with the other data.

There is a short term shift averaging approximately six percent r.h. at all ambient temperatures. It is possible that this is primarily an exercising effect. Since the long term shift as shown in Table 9 is in a direction opposite to the short term shift, this effect might also be reduced by an exercise routine. It is also possible that this effect could be modified by controlled storage methods. It should be noted that there was no appreciable change in sensitivity at 20°C after storage for five months. The primary change that did occur was that the absolute output voltage decreased over the entire humidity range.

In general, polynomial equations can be obtained that represent the calibration data with a standard deviation of approximately 3 percent r.h. except at -40°C where, probably due to the reduced sensitivity, the standard deviation is 18 percent r.h.

It should be pointed out that in all the calibrations performed, only the sensor was subjected to the humidities and temperature indicated. The associated electronics was always maintained at room temperature and humidity (approximately 24°C and 40 percent r.h.).

This sensor is convenient and easy to use. It does not appear to be as useful at low temperatures or low relative humidities as at higher temperatures and higher relative humidities. Although there is no unequivocal correlation, the sensors with high sensitivity appear to behave more favorably under ambient temperature changes, aging and direction of r.h. change. It might therefore be possible to choose the more favorable sensors by a simple selection routine involving calibration at only two relative humidities.

The calibration data for each sensor were fitted by means of least squares regression to a polynomial of the following form:

$$r.h. = \sum_{i=0}^{n} a_i V^i \qquad (1)$$

where r.h. is the relative humidity in percent, V is output voltage in volts, and n has a value between 2 and 4. As a general rule, n was 4 at the higher ambient temperatures and higher relative humidity spans.

The values given in Table 2 were obtained by solving equation (1) for V at fixed values of r.h. These values of V were then substituted into the following equation to obtain the sensitivity, S; in mV/percent r.h.:

$$S = \frac{1000.}{\sum_{i=1}^{n} i\, a_i V^{(i-1)}} \qquad (2)$$

Mean differences, $\overline{\Delta(r.h.)}$, as given in Table 5 through 8, were obtained by solving the following equation:

$$\overline{\Delta(r.h.)} = \frac{\sum_{i=0}^{n}\left[\frac{a_i - b_i}{i + 1}\left(v_2^{i+1} - v_1^{i+1}\right)\right]}{V_2 - V_1} \tag{3}$$

where a_i and b_i are the coefficients of the two equations being compared as determined by equation 1 and V_1 and V_2 are the limits of output voltage involved in the comparison.

In Tables 3 and 4 column 3a is given by:

$$r.h. = \sum_{i=0}^{n} b_i \, v_1^i \tag{4}$$

Column 3b is given by

$$r.h. = \sum_{i=0}^{n} b_i \, v_2^i \tag{5}$$

Column 4a is given by

$$r.h. = \sum_{i=0}^{n} a_i \, v_1^i \tag{6}$$

Column 4b is given by

$$r.h. = \sum_{i=0}^{n} a_i \, v_2^i \tag{7}$$

and Column 5 is given by

$$C = \overline{\Delta(r.h.)}/20 \tag{8}$$

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where C is the mean temperature coefficient and $\overline{\Delta r.h.}$ is obtained from solution of equation 3.

Values of $|Max|$ as given in Tables 5 through 8 were obtained by solution of the following equation:

$$|Max \ | \ = \ |\sum_{i=0}^{n}(a_i - b_i) \ v_{Max}^i|$$ (9)

V_{Max} is the value of V between V_1 and V_2 which gives the largest absolute value for $|Max|$.

Table 9 is a table of residual standard deviations, σ, as given by the following equation:

$$\sigma \ = \ \left[\frac{\sum_{j=1}^{m}\left((r.h.)_j - \sum_{i=0}^{n}a_i \ v_j^i\right)^2}{(m - n \ )} \right]^{1/2}$$ (10)

where V_j are measured output voltages obtained at corresponding $(r.h.)_j$ humidities and m is the total number of calibration points. The values of a_i are the values obtained by the least squares solution resulting in equation 1.
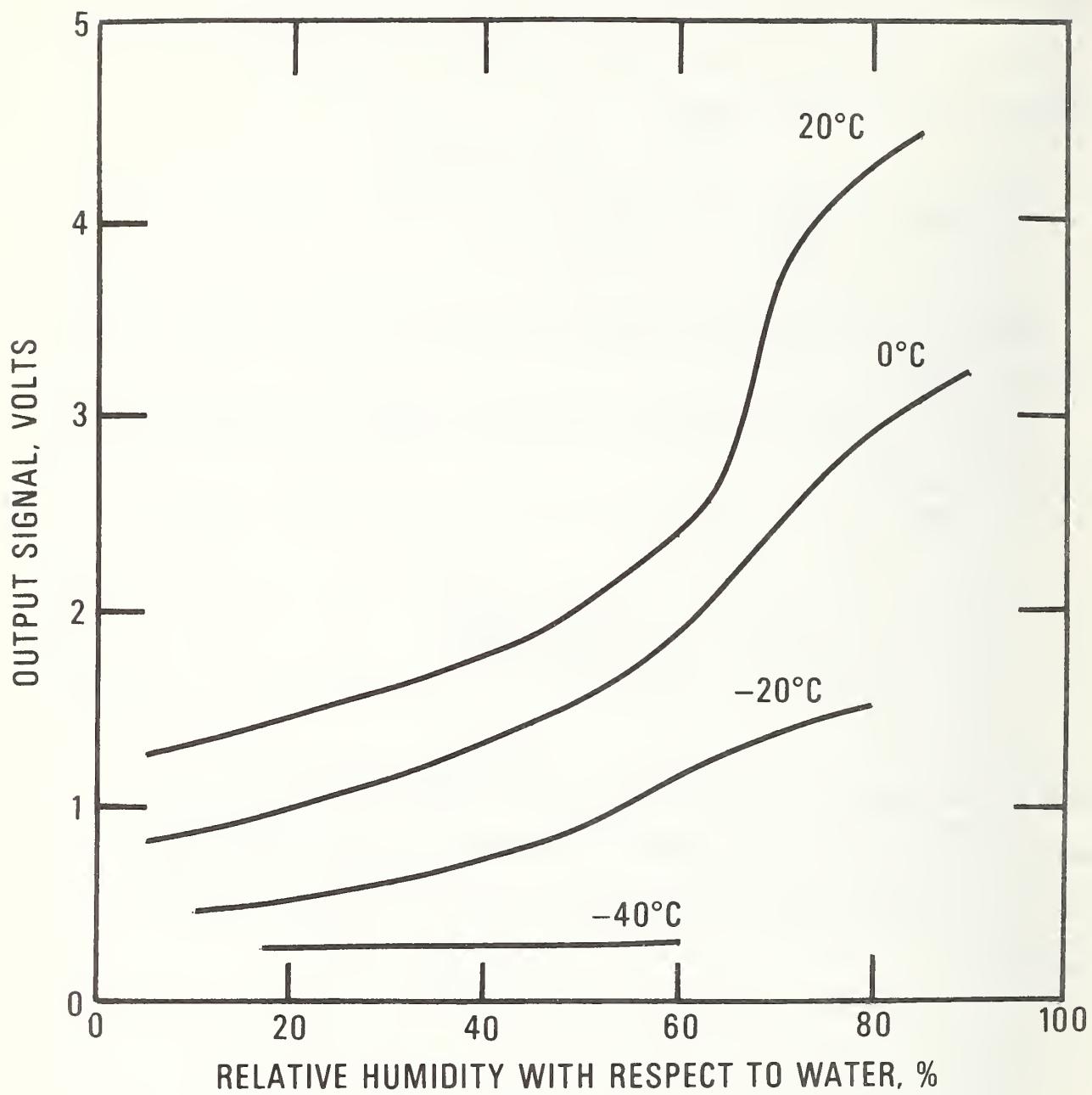
Figure 1. Output Voltage vs Relative Humidity for Sensor #2.
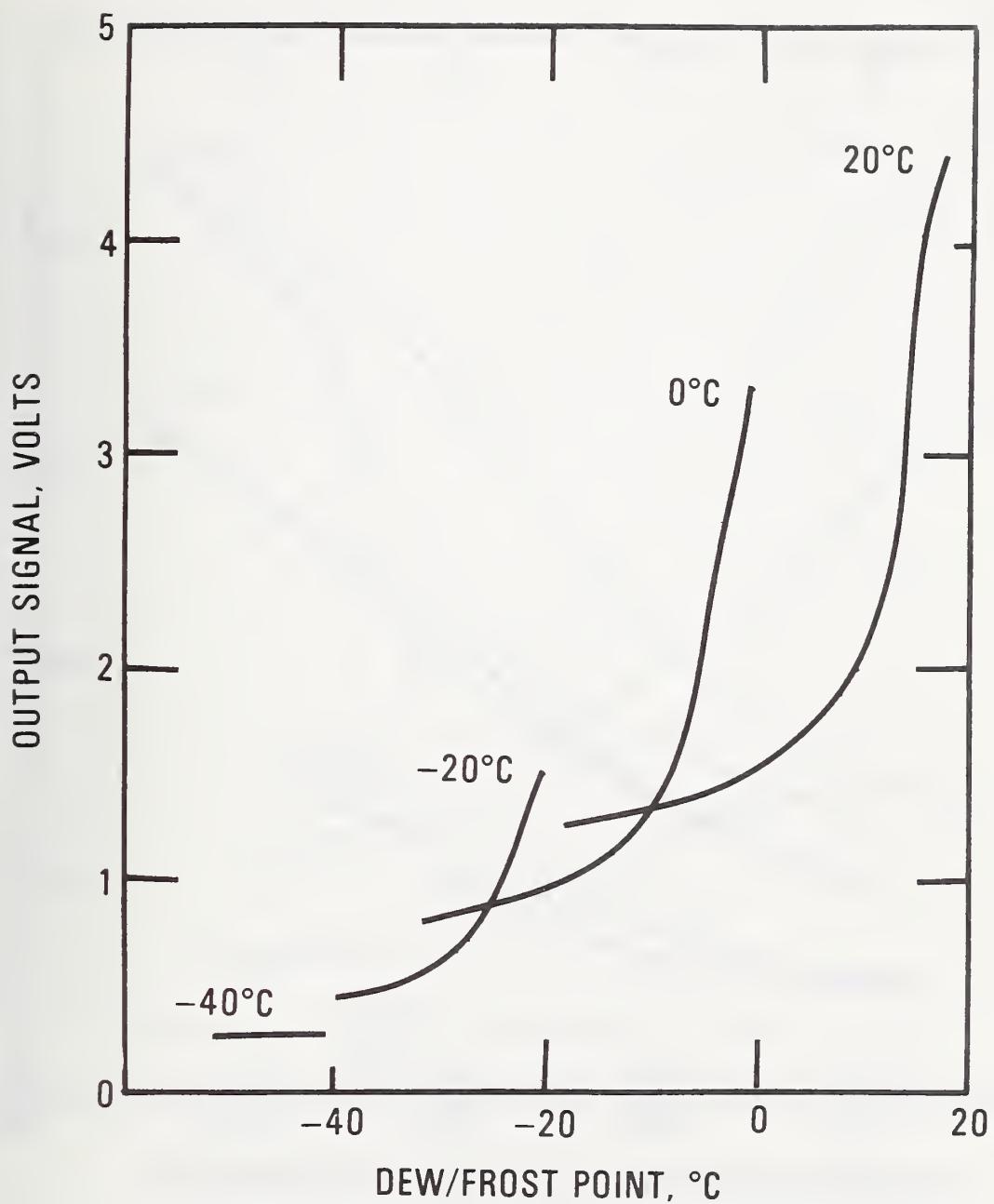
Figure 2. Output Voltage vs Dew/Frost Point for Sensor #2.
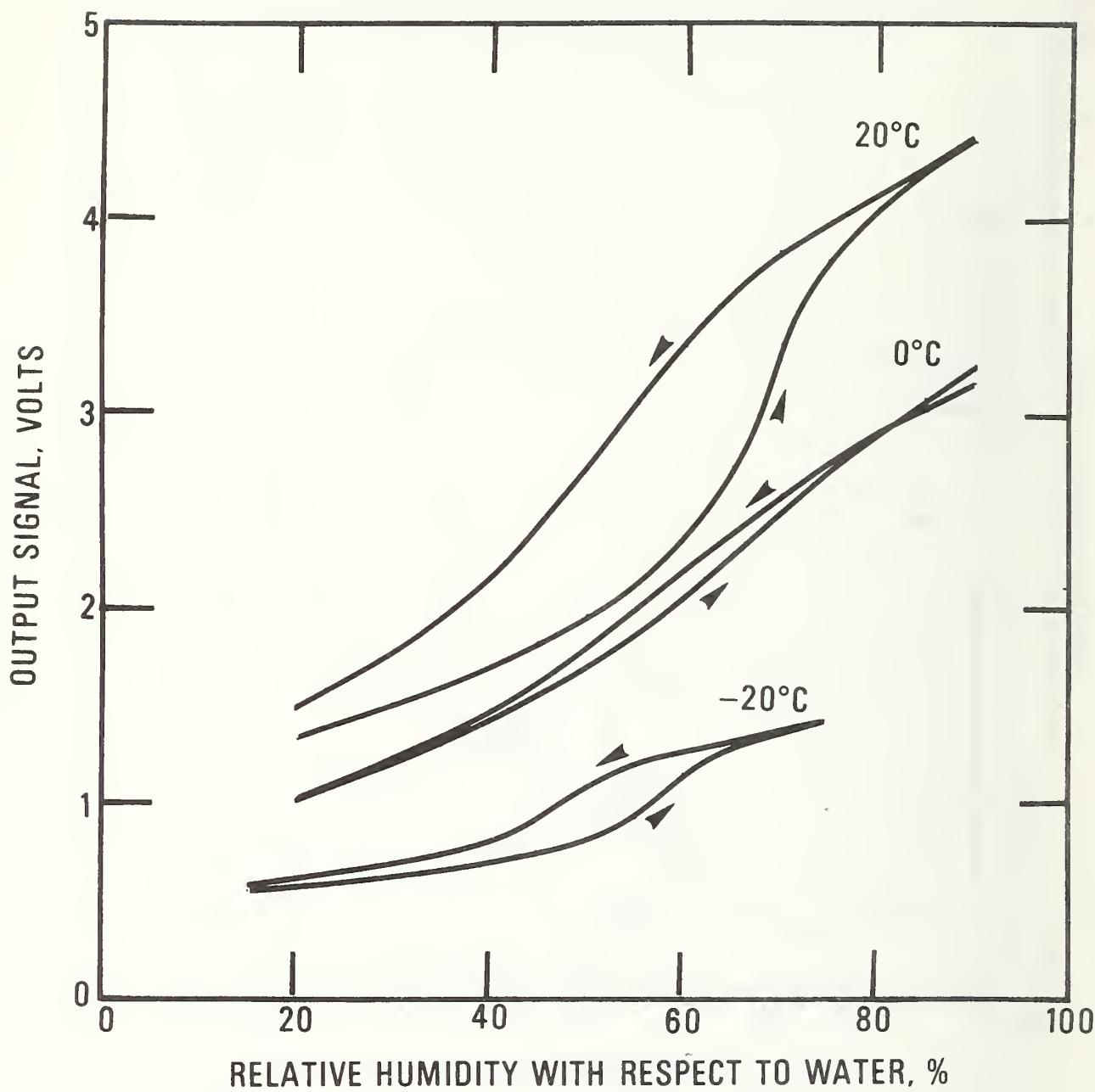
Figure 3. First Cycle Hysteresis for Sensor #2.
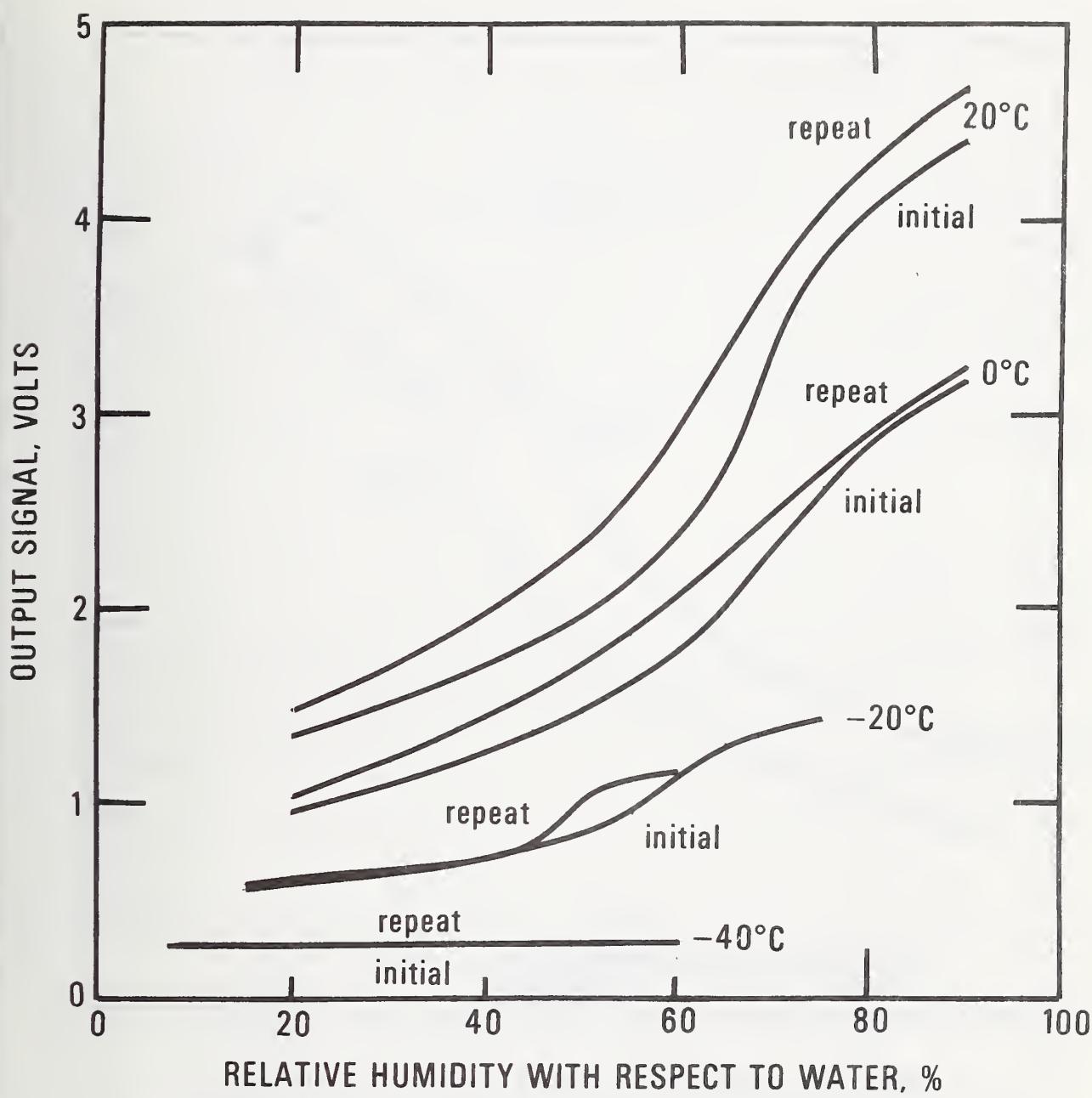
Figure 4. Short Term Repeatability for Sensor #2.
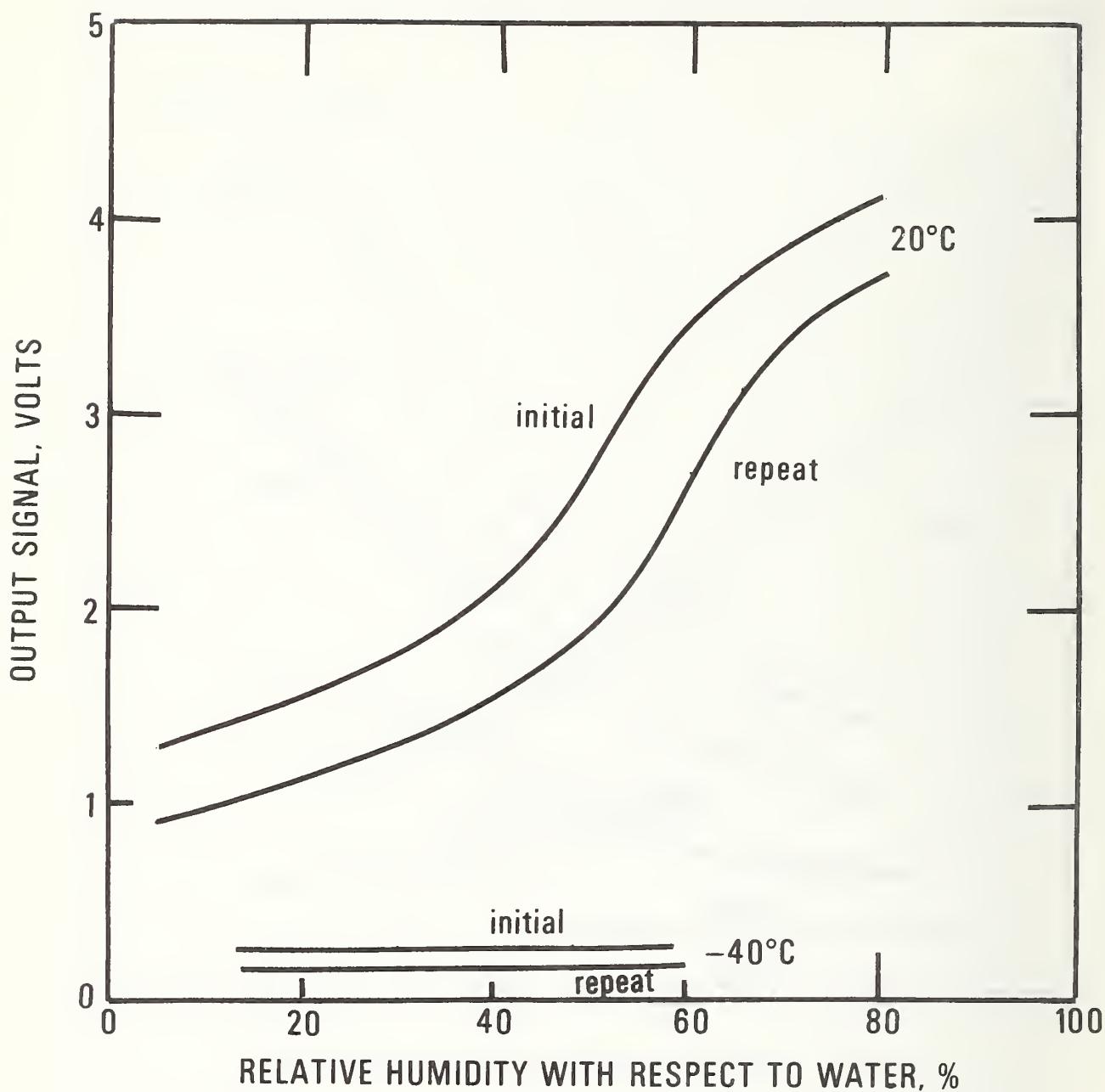
Figure 5. Long Term Repeatability for Sensor #2.

Table 1

Testing Spans

Ambient Temperature,°C			
20	0	-20	-40
Testing spans, percent relative humidity			
0.1 to 0.5			
0.8 to 4.3	0.4 to 2.1		
5.2 to 26.0	3.3 to 16.4	2.0 to 9.8	1.9 to 9.1
19.4 to 89.5	19.5 to 90.3	15.4 to 72.9	13.3 to 58.1
Testing spans in dew/frost point[1],°C			
-53 to -40	-53 to -40	-53 to -40	-68 to -56 -53 to -41
-36 to -20	-36 to -20	-36 to -21	
-18 to 0	-19 to -1		
- 4 to 18			

[1]
   Dew-point temperatures above 0°C; frost point for temperatures below 0°C.

Table 2

Sensitivity

| Sensor | Ambient Temperature °C | Relative Humidity, Percent | | | | |
| | | 10 | 30 | 50 | 70 | 90 |
		Sensitivity, mV/percent r.h.				
1	20	16	23	52	55	24
	0	15	21	39	45	23
	−20	7	11	42	12	
	−40	1.9	1.9	1.9		
2	20	12	16	28	117	23
	0	11	16	27	59	24
	−20	6	9	26	16	
	−40	.5	.5	.5		
3	20	17	25	53	63	26
	0	16	22	41	51	25
	−20	6	9	27	15	
	−40	.7	.7	.7		
4	20	21	30	55	76	37
	0	19	24	34	55	50
	−20	7	11	27	18	
	−40	1.7	1.7	1.7		
5	20	10	13	20	37	27
	0	5	7	11	22	13
	−20	2	3	6	8	
	−40	−4.8	−4.8	−4.8		
6	20	11	11	13	18	54
	0	4	5	8	15	8
	−20	2	2	4	5	
	−40	0.2	0.2	0.2		

Table 2 (cont'd)

Sensitivity

Sensor	Ambient Temperature °C	Relative Humidity, Percent				
		10	30	50	70	90
		Sensitivity, mV/percent r.h.				
7	20	23	25	30	41	54
	0	11	14	20	37	40
	-20	5	8	12	15	
	-40	-0.6	-0.6	-0.6		
8	20	-17	16	15	18	45
	0	6	8	11	18	17
	-20	2	3	6	7	
	-40	0.2	0.2	0.2		
9	20	-12	14	14	17	24
	0	22	26	32	38	39
	-20	2	2	4	7	
	-40	0.1	0.1	0.1		
10	20	30	39	51	56	45
	0	22	26	32	38	39
	-20	8	13	25	14	
	-40	1.0	1.0	1.0		
Mean	20	11	21	33	50	36
	0	13	17	26	38	28
	-20	4	7	18	12	
	-40	0.2	0.2	0.2		

Table 3

Temperature Coefficient in the Ambient Temperature Range of 20 to 0°C

Sensor	Overlapping Voltage Span Volts	Computed Relative Humidity Limits at 20°C Percent r.h.	Computed Relative Humidity Limits at 0°C Percent r.h.	Mean Temperature Coefficient Percent r.h./°C
1	1.113 to 3.3195	14.01 to 60.29	31.28 to 91.28	0.89
2	1.340 to 3.250	14.54 to 67.33	40.85 to 91.87	0.85
3	0.8586 to 3.3144	13.75 to 61.97	28.17 to 91.42	0.77
4	1.4878 to 4.0341	12.33 to 66.94	33.26 to 90.83	1.00
5	0.7171 to 1.4832	12.75 to 62.33	45.25 to 91.57	1.32
6	1.0522 to 1.2970	11.96 to 44.15	69.86 to 91.08	2.48
7	1.2821 to 2.7679	13.09 to 67.32	48.36 to 90.44	1.41
8	1.5916 to 1.7961	10.31 to 30.57	79.77 to 90.74	3.21
9	1.4038 to 1.5575	11.52 to 32.14	77.89 to 91.59	3.08
10	1.4540 to 3.4441	12.40 to 59.25	33.32 to 90.41	1.25
Mean				1.63

Table 4

Temperature Coefficient in the Ambient Temperature Range of 0 to -20°C

Sensor	Overlapping Voltage Span (Volts)		Computed Relative Humidity Limits at 0°C (Percent r.h.)		Computed Relative Humidity Limits at -20°C (Percent r.h.)		Mean Temperature Coefficients (Percent r.h./°C)
1	0.7131 to	1.5055	8.66 to	45.86	41.38 to	72.65	1.24
2	0.8464 to	1.4058	6.90 to	43.99	47.35 to	72.19	1.59
3	0.4926 to	1.4383	7.68 to	48.58	36.28 to	72.49	1.21
4	0.9244 to	1.6812	6.50 to	40.48	42.23 to	72.68	1.61
5	0.4243 to	0.6163	3.29 to	34.00	49.79 to	72.41	2.08
6*	0.5984 to	0.5955	1.55 to	2.45	72.47 to	73.05	(3.54)
7	0.6592 to	1.0033	0.75 to	30.90	48.92 to	72.44	2.22
8	0.7532 to	0.7967	-0.13 to	7.74	66.67 to	72.68	3.29
9*	0.7108 to	0.6991	-0.95 to	2.55	72.50 to	74.50	(3.63)
10	0.7906 to	1.4825	5.79 to	34.36	38.58 to	72.56	1.69
Mean							1.87

* No overlapping voltage existed. The voltage span used was from the -20°C high voltage to the 0°C low voltage resulting in extrapolated calculations.

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Table 5

First Cycle Hysteresis

Ambient Temperature, °C

		20				0			−20		−40[1]
		Relative Humidity Span, Percent									
		0.1 to 0.5	0.8 to 4.3	5.2 to 26.0	19.4 to 89.5	0.4 to 2.1	3.3 to 16.4	90.3[2] to 19.5	2.0 to 9.8	15.8 to 72.9	13.3 to 57.8
Sensor		Hysteresis, Percent r.h.									
1	Mean	−0.16	0.01	2.09	5.89	−0.16	0.93	1.40	0.21	6.25	6.43
	|Max|	0.20	0.21	2.82	10.58	0.40	1.39	2.52	0.38	8.17	7.52
2	Mean	−0.10	0.05	2.26	10.56	−0.12	0.95	1.87	0.48	7.56	5.33
	|Max|	0.22	0.27	3.04	15.86	0.31	1.40	3.49	0.50	10.05	7.65
3	Mean	−0.15	0.13	2.94	6.67	−0.04	1.40	1.88	0.90	8.56	4.00
	|Max|	0.16	0.26	4.00	11.88	0.16	2.02	3.22	1.30	11.71	5.57
4	Mean	−0.11	0.06	2.68	7.77	−0.11	1.42	1.80	0.93	6.26	9.21
	|Max|	0.19	0.19	3.66	10.92	0.32	2.01	3.19	0.98	7.88	12.40
5	Mean	−0.03	0.02	2.17	11.13	−0.05	1.22	2.37	0.52	8.03	−7.94
	|Max|	0.07	0.21	3.09	17.74	0.19	1.74	4.41	0.53	15.22	22.16
6	Mean	−0.04	−0.02	2.05	12.02	−0.12	1.14	2.82	−0.21	9.41	4.11
	|Max|	0.09	0.22	2.91	19.28	0.31	1.62	4.68	0.38	15.93	5.65
7	Mean	−0.07	0.14	4.01	2.57	−0.61	2.07	1.37	0.05	8.18	7.81
	|Max|	0.17	0.51	5.66	16.43	0.62	3.11	3.17	0.13	19.83	12.02
8	Mean	−0.03	−0.02	2.31	13.58	−0.09	1.25	2.69	0.05	11.86	11.15
	|Max|	0.07	0.25	3.26	23.49	0.25	1.77	4.69	0.35	21.52	17.23
9	Mean	−0.03	−0.03	1.51	12.44	−0.11	0.69	1.81	−0.17	7.28	1.62
	|Max|	0.09	0.22	2.18	22.21	0.29	1.03	3.02	0.53	16.14	5.00
10	Mean	−0.16	0.14	3.42	4.69	−0.22	1.82	1.66	0.23	6.88	8.94
	|Max|	0.22	0.28	4.68	7.84	0.48	2.62	2.48	0.38	13.36	13.80
Mean	Mean	−0.09	0.05	2.55	8.74	−0.16	1.29	1.97	0.31	8.03	5.02
	|Max|	0.15	0.26	3.53	15.62	0.33	1.87	3.49	0.55	13.98	10.90
Degree of fit		2	3	3	4	2	3	4	2	4	3

[1] This is an open loop.

[2] This is not a first cycle.

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Table 6

Direction Effect

Sensor		Ambient Temperature, °C		
		20	0	-20
		Relative Humidity Span, Percent		
		0-75	7-75	15-59
Sensor		Difference, Percent r.h.		
1	Mean	7.18	4.00	4.34
	|Max|	11.47	8.25	10.69
2	Mean	9.79	6.27	5.56
	|Max|	15.10	10.13	8.82
3	Mean	6.85	4.28	5.36
	|Max|	11.05	8.05	13.89
4	Mean	6.08	4.12	4.77
	|Max|	8.53	6.85	7.74
5	Mean	8.55	7.60	5.54
	|Max|	12.07	10.02	8.61
6	Mean	8.44	8.34	6.24
	|Max|	11.03	11.03	8.68
7	Mean	6.28	8.26	3.85
	|Max|	8.94	10.94	10.82
8	Mean	8.61	10.13	7.89
	|Max|	14.10	14.08	9.91
9	Mean	7.99	8.15	4.26
	|Max|	11.27	11.42	6.79
10	Mean	4.55	3.55	4.79
	|Max|	6.76	4.66	8.70
Mean	Mean	7.43	6.47	5.26
	|Max|	11.03	9.54	9.46

Table 7

Short term Repeatability

Sensor		Ambient Temperature, °C			
		20	0	-20	-40
		Relative Humidity Span, Percent			
		19 to 89	19 to 90	15 to 59	13 to 58
		Difference on repetition, Percent r.h.			
1	Mean	-2.76	-2.43	-2.96	-11.70
	|Max|	5.34	4.36	8.52	23.87
2	Mean	-7.07	-5.03	-4.34	- 9.22
	|Max|	10.13	8.24	8.02	12.56
3	Mean	-4.60	-2.01	-5.15	-11.35
	|Max|	9.01	2.61	13.43	26.22
4	Mean	-5.43	-2.47	-2.71	-14.18
	|Max|	8.22	4.40	8.11	32.60
5	Mean	-7.32	-7.82	-6.64	- 3.19
	|Max|	12.10	10.86	10.87	13.01
6	Mean	-7.73	-8.25	-7.22	- 2.48
	|Max|	13.21	12.73	12.17	4.75
7	Mean	-0.48	-6.65	-9.46	1.00
	|Max|	9.95	16.31	20.17	4.74
8	Mean	-9.12	-10.88	-9.85	6.14
	|Max|	16.95	20.17	17.77	19.59
9	Mean	-8.82	- 9.14	-8.21	-11.44
	|Max|	16.39	15.12	12.41	32.15
10	Mean	-3.10	- 2.65	-4.56	- 7.36
	|Max|	4.89	4.81	10.53	15.96
Mean	Mean	-5.64	- 5.73	-6.11	- 6.38
	|Max|	10.62	9.96	12.20	18.54

Table 8

Long Term Repeatability

Sensor		Ambient Temperature, °C	
		20	-40
		Relative Humidity Span, Percent	
		5 to 75	27 to 60
		Difference on Repetition, Percent r.h.	
2	Mean	14.13	
	|Max|	25.39	
3	Mean	11.85	
	|Max|	16.80	
4	Mean	-0.94	-24.23
	|Max|	4.07	24.91
5	Mean	0.49	19.31
	|Max|	6.17	20.30
6	Mean	18.89	
	|Max|	23.61	
7	Mean	22.69	
	|Max|	31.56	
8	Mean	20.99	
	|Max|	25.21	
9	Mean	22.36	
	|Max|	28.50	
10	Mean	7.31	10.44
	|Max|	9.54	18.86
Mean	Mean	13.09	
	|Max|	18.98	

Table 9

Calibration Scatter

Based on Least Squares Cubic Fits

	Ambient Temperature, °C			
	20	0	-20	-40
	No. of Points forming Calibration Curve			
	24	15	10	11
	Relative Humidity Span, Percent			
	0 to 90	7 to 90	10 to 73	5 to 58
Sensor	Estimate of the standard deviation, Percent r.h.			
1	3.6	2.8	1.6	20.2
2	4.3	3.3	1.5	17.0
3	3.1	2.4	2.4	22.7
4	2.2	2.0	2.3	21.1
5	3.6	3.7	2.8	22.4
6	4.8	4.0	3.0	18.3
7	2.9	5.0	3.6	13.5
8	4.5	5.7	4.3	13.1
9	5.6	4.8	3.5	16.6
10	1.7	2.1	2.1	17.3
Mean	3.6	3.6	2.7	18.2

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

A laboratory study was made of the performance of "Brady Array" humidity sensors[b] over a range of ambient temperatures from -40°C to +20°C encompassing relative humidities from 0 to 90 percent. Information was obtained on such characteristics as sensitivity, hysteresis, temperature effect, short-term and long-term repeatability.

17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons) "Brady Array" sensors, electric hygrometer, humidity, humidity sensor, moisture measurement, relative humidity, water vapor measurement.

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